BAKING SYSTEM HAVING A HEAT PIPE

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a baking system for use in a process of manufacturing semiconductor devices. More particularly, the present invention relates to a baking system having a heat pipe as a cooling unit.

2. Description of the Related Art

[0002] A photolithographic process, which is one type of process performed during the manufacture of a semiconductor device, includes a coating process of coating a photoresist layer on a wafer, a pre-baking process of baking the coated photoresist layer before exposure, and a post-exposure baking process of baking the photoresist layer after exposure, to form a predetermined pattern in the photoresist layer.

[0003] In a photolithographic process, a baking temperature varies according to a type of photoresist layer and a type of baking process. For example, the baking process may be performed at a temperature of 150 °C or 90 °C depending on particular circumstances. Accordingly, a widely used baking apparatus includes a heating system and a cooling system to adjust the baking temperature according to the particular circumstances.

[0004] FIGS. 1 through 3 illustrate sectional views of cooling systems of conventional baking apparatuses (hereinafter, referred to as "conventional cooling systems").

[0005] In a first conventional cooling system, as shown in FIG. 1, coolant paths 56 and 57, through which a coolant flows, are installed in a plate 54. Coolant circulates through the coolant paths 56 and 57 and cools a heating plate 51. The first conventional cooling system additionally includes a heater 52, a lift pin 53, and a cooling plate 55. Coolant supply pipelines 60 and 61 include switching valves 62 and 63, respectively, and terminate at a drain 64. The first conventional cooling system further includes a temperature sensor 65, a unit controller 66, a temperature adjuster 67, a solenoid valve 68, and a power supply 69. A system controller 80 controls operations of the entire system.

[0006] In a second conventional cooling system, as shown in FIG. 2, a plurality of nozzles 74 is installed under a heating plate 70 that acts as a baking plate. A spray of a fluid from the nozzles 74 onto the heating plate 70 is used to cool the heating plate 70. The second conventional cooling system further includes a heater 71, a guide 83, an inner case 85, a support ring 87, a cooling plate 93, and a black plate 96.

[0007] A third conventional cooling system 30, as shown in FIG. 3, includes a cooling plate 99 in which a Peltier device 101 is embedded. The Peltier device 101 adjusts a temperature of the cooling plate 99 to a predetermined temperature. The third conventional cooling system 30 further includes a power controller 102 for supplying power to the Peltier device 101, a temperature adjuster 103 for adjusting the temperature of the Peltier device

101, and a proportional integral derivative (PID) control parameter altering unit 105. In addition, the cooling system 30 includes a flow path 111 used for radiating heat generated in the Peltier device 101, a lifting pin 90 for lifting a wafer W, a penetration pin 91, and a proximity pin 92 for supporting the wafer W. A temperature sensor 104 senses a temperature of the cooling plate 99.

[0008] In the above-described conventional cooling systems a temperature deviation between different regions of a baking plate is very large. More specifically, the entire baking plate cannot be uniformly cooled. In addition, a significant amount of time is required until a temperature is uniformly distributed after a cooling process starts. These disadvantages degrade semiconductor device manufacturing productivity.

[0009] As these problems of the conventional cooling systems have been highlighted, various alternatives have been proposed. One such alternative requires a plurality of baking plates, set to different temperatures, to be installed in a cooling system. In this case, however, although a cooling time may be reduced, a single spinner is required to include the plurality of baking plates and thus becomes undesirably large.

SUMMARY OF THE INVENTION

[0010] In an effort to overcome at least some of the above-described disadvantages, the present invention provides a baking system that is able to uniformly cool an entire top surface of a hot plate and effectively reduce a cooling time.

[0011] In accordance with a feature of an embodiment of the present invention, there is provided a baking system including a heat pipe including a top surface for receiving a wafer to be baked, the heat pipe to be filled with a predetermined amount of working fluid and having wicks formed on sides and a ceiling thereof for supplying the working fluid, a heater for heating the top surface by heating the working fluid, a subsidiary cooling system, which contains a liquid coolant that is to be exchanged with the working fluid from the heat pipe through circulation, a connection pipe for providing fluid communication between the heat pipe and the subsidiary cooling system to circulate the working fluid and the liquid coolant, and a control unit, which is installed in the connection pipe, for controlling a flow of the working fluid and the liquid coolant through the connection pipe.

[0012] The connection pipe may include an inlet flow path and an outlet flow path for providing fluid communication between the heat pipe and the subsidiary cooling system. The connection pipe may include an outlet connection pipe for providing fluid communication from the heat pipe to the

subsidiary cooling system and an inlet connection pipe for providing fluid communication from the subsidiary cooling system to the heat pipe.

[0013] The control unit may include an outlet fluid control unit installed in the outlet connection pipe and an inlet fluid control unit installed in the inlet connection pipe. The outlet fluid control unit may be an automated pump or a valve and the inlet fluid control unit may be a valve, an automatic pump, or a manual pump.

[0014] The control unit may include a first outlet fluid control unit and a second outlet fluid control unit sequentially installed in the outlet connection pipe and an inlet fluid control unit installed in the inlet connection pipe. The first outlet fluid control unit may be an automatic valve or a manual valve, the inlet fluid control unit may be an automatic valve, a manual valve, or a pump, and the second outlet fluid control unit may be a pump.

[0015] The subsidiary cooling system may include a coolant storage tank for storing the liquid coolant, the coolant storage tank having a wick formed therein, a cooling unit installed at the coolant storage tank for cooling the working fluid supplied from the heat pipe, and a pressurizing unit for pressurizing the liquid coolant during a process of cooling the top surface.

[0016] The subsidiary cooling system may include a first coolant storage tank for storing the liquid coolant and a first cooling system installed at the first coolant storage tank for cooling the working fluid supplied from the heat pipe. Further, there may be included a second coolant storage tank in fluid

communication with the first coolant storage tank, wherein the first cooling system extends to the second coolant storage tank. Alternatively, there may be included a second coolant storage tank in fluid communication with the first coolant storage tank and a second cooling system installed at the second coolant storage tank. Further, there may be included an intermediate connection pipe for providing fluid communication between the first coolant storage tank and the second coolant storage tank and an intermediate fluid control unit installed in the intermediate connection pipe. The control unit may be a pump or a valve.

[0017] The baking system may further include a subsidiary heater installed in the connection pipe between an inlet of the heat pipe and the subsidiary cooling system to heat a fluid flowing through the connection pipe. Alternatively, the baking system may further include a subsidiary heater installed at the first coolant storage tank to heat a fluid supplied into the heat pipe.

[0018] The working fluid may be water, deionized water, acetone, or methyl.

[0019] In accordance with a feature of another embodiment of the present invention, there is provided a baking system including a heat pipe including a top surface for receiving a wafer to be baked and an inlet side and an outlet side, the heat pipe to be filled with a predetermined amount of working fluid and having wicks formed on sides and a ceiling thereof for supplying the working fluid, a heater for heating the top surface of the heat pipe by heating

the working fluid, a connection pipe, a first end of which is connected to the outlet side of the heat pipe, and a second end of which is connected to the inlet side of the heat pipe, a cooling unit installed in the connection pipe for cooling the working fluid flowing through the connection pipe, and a control unit for controlling the working fluid.

[0020] The cooling unit may be installed to wrap around a portion of the connection pipe. The control unit may include an outlet fluid control unit installed in the connection pipe between the outlet side of the heat pipe and the cooling unit and an inlet fluid control unit installed in the connection pipe between the inlet side of the heat pipe and the cooling unit. The outlet fluid control unit and the inlet fluid control unit may be an automatic valve, a manual valve, or a pump.

[0021] A baking system according to an embodiment of the present invention is able to uniformly cool an entire region of a hot plate in a relatively short amount of time to stabilize the temperature of the hot plate. Further, a time required to heat the hot plate may be decreased using a subsidiary heater, thus improving semiconductor device manufacturing productivity.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The above and other features and advantages of the present invention will become more apparent to those of ordinary skill in the art by describing in detail illustrative embodiments thereof with reference to the attached drawings in which:

[0023] FIGS. 1 through 3 illustrate sectional views of a first through a third conventional cooling system, respectively;

[0024] FIGS. 4 through 9 illustrate partial sectional views of baking systems according to a first through a sixth embodiment of the present invention, respectively;

[0025] FIG. 10 is a graph of simulation results showing a cooling efficiency of a conventional baking system using natural cooling;

[0026] FIGS. 11 through 13 are graphs of simulation results showing a cooling efficiency of a conventional baking system, in which a cooling line is buried in a hot plate;

[0027] FIG. 14 is a graph of simulation results showing a cooling efficiency of a conventional baking system, in which a cooling line is installed under a heater;

[0028] FIGS. 15 and 16 illustrate a partial front view and a plan view, respectively, of the conventional baking system with the cooling line buried in the hot plate;

[0029] FIG. 17 illustrates a partial front view of the conventional baking system with the cooling line installed under the heater; and

[0030] FIGS. 18 through 20 are graphs of simulation results showing a cooling efficiency of the baking systems according to the embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0031] Korean Patent Application No. 2003-21920, filed on April 8, 2003, and entitled: "Baking System," is incorporated by reference herein in its entirety.

[0032] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplary embodiments of the invention are shown. The invention may, however, be embodied in different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the figures, the dimensions of layers and regions are exaggerated for clarity of illustration. Like reference numerals refer to like elements throughout. In the context of the present invention, a term "working fluid" describes a fluid in a heat pipe that operates either to heat or to cool a top surface of the heat pipe. A term "liquid coolant" describes a fluid in a coolant storage tank that circulates to replace the working fluid in the heat pipe and operates to cool the top surface of the heat pipe.

<u>First Embodiment</u>

[0033] As shown in FIG. 4, a baking system according to a first embodiment includes a main body P1 and a subsidiary cooling system P2. The main body P1 includes a heat pipe 100 and a heater 102 contacting a bottom of the heat pipe 100. The subsidiary cooling system P2 includes a coolant

storage tank 106, which is partially filled with a liquid coolant 104b, a cooling unit 110 for cooling the liquid coolant 104b, and a pressurizing unit 109 for forcibly circulating the liquid coolant 104b through the heat pipe 100.

[0034] Wicks W1 and W2 are formed on inner sides of and on a center of the ceiling of the heat pipe 100, respectively. In the context of the present invention, the term wicks may also include wick plates WP1 and WP2, as shown in FIG. 4. Wicks similar to the wicks W1 and W2 may be formed on an inside of the coolant storage tank 106. More specifically, the wicks may be formed on inner sides of and a ceiling of the coolant storage tank 106 so that a high-temperature working fluid, which flows into the coolant storage tank 106, can move along the sides of the coolant storage tank 106 to the ceiling thereof due to the capillarity attraction of the wicks and evaporate. In this process, the high-temperature working fluid flowing into the coolant storage tank 106 is cooled. More specifically, the subsidiary cooling system P2 includes the coolant storage tank 106 functioning as a heat pipe. The pressurizing unit 109 heats the vapor above the liquid coolant 104b contained in the coolant storage tank 106 and pressurizes the liquid coolant. Preferably, the pressurizing unit 109 does not cause physical transformation of the coolant storage tank 106.

[0035] When a baking process is performed, as shown in FIG. 4, a wafer W is loaded on a top surface S1 of the heat pipe 100, and the top surface S1 of the heat pipe 100, i.e., a hot plate surface, is heated to a predetermined

temperature, e.g., 100 °C to 150 °C. After the baking process is finished and the wafer W is removed from the top surface S1, the heat pipe 100 cools the top surface S1, which was heated in the baking process, to a predetermined temperature.

[0036] In order to cool the top surface S1, the heat pipe 100 is filled with a predetermined amount of working fluid 104a.

[0037] During a baking process, the working fluid 104a transmits heat from the heater 102 to the top surface S1 of the heat pipe 100 to heat the top surface S1. More specifically, the heat transmitted from the heater 102 causes the working fluid 104a to evaporate into an upper space 112 and contact the ceiling of the heat pipe 100, thus heating the top surface S1 of the heat pipe 100.

[0038] During a cooling process, the working fluid 104a is supplied along the wicks W1 and W2 to the ceiling of the heat pipe 100 and evaporates, thereby cooling the hot plate surface, i.e., the top surface S1 of the heat pipe 100. Since the wicks W1 are uniformly formed on the entire ceiling of the heat pipe 100, the working fluid 104a is uniformly supplied to the entire ceiling of the heat pipe 100. In addition, the working fluid 104a is affected by the capillarity attraction of the wicks W1 and W2 and is rapidly supplied to the entire ceiling of the heat pipe 100 during the cooling process. Thus, the entire top surface S1 of the heat pipe 100 is cooled in a relatively short amount of time. The vapor, generated in the cooling process, passes

through the upper space 112 and contacts the working fluid 104a, whose temperature is lower than that of the vapor. Thus, the vapor condenses again into the working fluid 104a.

[0039] The working fluid 104a may be water, i.e., deionized water, acetone, methyl or any suitable liquid.

[0040] While the top surface of the heat pipe 100 is being cooled, if the working fluid 104a is replaced by another fluid, whose temperature is lower than that of the working fluid 104a, the cooling efficiency of the heat pipe 100 will improve. For this purpose, the liquid coolant 104b contained in the coolant storage tank 106 of the subsidiary cooling system P2 is prepared. The liquid coolant 104b is preferably maintained at a temperature lower than that of the working fluid 104a.

[0041] While the top surface S1 of the heat pipe 100 is being cooled, to improve the cooling efficiency of the heat pipe 100, fluid circulates between the subsidiary cooling system P2 and the heat pipe 100 until the top surface S1 is cooled to a desired temperature.

[0042] Specifically, an outlet flow path L1 and an inlet flow path L2 are installed between the heat pipe 100 and the subsidiary cooling system P2 to provide fluid communication between the heat pipe 100 and the subsidiary cooling system P2. A valve 108 for controlling the flow of fluid is installed in the outlet and inlet flow paths L1 and L2 such that the fluid circulates only during the cooling process. Alternatively, the valve 108 may be a pump.

[0043] When the cooling process of the top surface S1 of the heat pipe 100 starts, the valve 108 is opened and simultaneously, the pressurizing unit 109, such as a Peltier device, of the subsidiary cooling system P2, pressurizes the liquid coolant 104b. As a result, some of the liquid coolant 104b is supplied via the inlet flow path L2 to the heat pipe 100, and the working fluid 104a of the heat pipe 100 is supplied via the outlet flow path L1 to the coolant storage tank 106. This fluid circulation is conducted continuously or periodically until the top surface S1 of the heat pipe 100 is cooled to a predetermined temperature, e.g., 100 °C. During the fluid circulation, the heated working fluid 104a of the heat pipe 100 flows into the coolant storage tank 106 of the subsidiary cooling system P2 and raises the temperature of the liquid coolant 104b stored in the coolant storage tank 106. However, the cooling unit 110, installed under the coolant storage tank 106, maintains the liquid coolant 104b at a constant temperature.

<u>Second Embodiment</u>

[0044] Referring to FIG. 5, a baking system according to a second embodiment includes a coolant storage tank 120 in fluid communication with the heat pipe 100. An outlet of the heat pipe 100 is connected to a side, e.g., a top of the coolant storage tank 120 by an outlet connection pipe 126. An inlet of the heat pipe 100 is connected to another side of the coolant storage tank 120 by an inlet connection pipe 128. During a cooling process, the working fluid 104a flows from the heat pipe 100 to the coolant storage

tank 120 via the outlet connection pipe 126. The working fluid 104a, which flows into the coolant storage tank 120, is cooled to a predetermined temperature, e.g., 23 °C, and is then returned to the heat pipe 100 via the inlet connection pipe 128.

[0045] The fluid circulation between the heat pipe 100 and the coolant storage tank 120 may be interrupted during a baking process and restarted during a process of cooling the top surface S1 of the heat pipe 100. To perform this interruption, an outlet fluid control unit 126a and an inlet fluid control unit 128a are installed in the outlet connection pipe 126 and the inlet connection pipe 128, respectively. The outlet fluid control unit 126a may be an automated pump or a valve. The inlet fluid control unit 128a may be a valve, an automatic pump or a manual pump.

[0046] In operation, while fluids, i.e., the working fluid and the liquid coolant, are circulating between the heat pipe 100 and the coolant storage tank 120, a level of the working fluid 104a in the heat pipe 100 may rise over time but is preferably maintained as constant as possible. Accordingly, the flow rate of the working fluid 104a flowing from the heat pipe 100 is preferably equal to that of the liquid coolant (not shown) flowing into the heat pipe 100. To maintain a constant flow rate, in a case where a diameter of the outlet connection pipe 126 is equal to that of the inlet connection pipe 128, a control function of the outlet fluid control unit 126a is preferably equal to that of the inlet fluid control unit 128a. Alternatively, when a diameter of the

outlet connection pipe 126 differs from that of the inlet connection pipe 128, a control function of the outlet fluid control unit 126a may be adjusted to differ from that of the inlet fluid control unit 128a such that the flow rate of the working fluid 104a from the heat pipe 100 is equal to that of the liquid coolant flowing into the heat pipe 100.

[0047] In addition, the working fluid 104a flowing from the heat pipe 100 into the coolant storage tank 120 via the outlet connection pipe 126 has a relatively high temperature, whereas the liquid coolant supplied from the coolant storage tank 120 to the heat pipe 100 via the inlet connection pipe 128 preferably has a relatively lower predetermined temperature, e.g., 23 °C. Thus, the working fluid 104a supplied to the coolant storage tank 120 is preferably cooled to the predetermined temperature of 23 °C. A cooling unit 124 is installed at the coolant storage tank 120 to cool the working fluid 104a. The cooling unit 124 may be provided on a top of the coolant storage tank 120, as shown, or may be installed under the coolant storage tank 120 as illustrated by reference numeral 124'.

[0048] In a case where the cooling unit 124 includes an evaporation unit (not shown) and a condensation unit (not shown), the evaporation unit may be installed on a top, a bottom and/or a side of the coolant storage tank 120, and the condensation unit may be installed in a region spaced apart from the evaporation unit.

Third Embodiment

[0049] Referring to FIG. 6, in a baking system according to a third embodiment of the present invention, a connection pipe 130 is installed outside the heat pipe 100 to circulate the working fluid 104a in the heat pipe 100 during the cooling of the top surface S1, i.e., the hot plate surface. An inlet of the connection pipe 130 is connected to the outlet of the heat pipe 100 and an outlet of the connection pipe 130 is connected to the inlet of the heat pipe 100. A cooling unit 132 is installed at a predetermined position along the connection pipe 130 so as to wrap around a portion of the connection pipe 130. The cooling unit 132 of the third embodiment performs the same function as the cooling unit 124 of the second embodiment. In particular, the cooling unit 132 cools the working fluid 104a flowing from the heat pipe 100 through the connection pipe 130 to a predetermined temperature. The outlet fluid control unit 126a, as described in connection with the second embodiment, is installed in the connection pipe 130 between the outlet of the heat pipe 100 and the cooling unit 132. In addition, the inlet fluid control unit 128a is installed in the connection pipe 130 between the inlet of the heat pipe 100 and the cooling unit 132.

Fourth Embodiment

[0050] Referring to FIG. 7, in a baking system according to a fourth embodiment of the present invention, a first coolant storage tank 134 and a second coolant storage tank 136 are installed outside the heat pipe 100.

The first coolant storage tank 134 and the second coolant storage tank 136 store the high-temperature working fluid 104a supplied from the heat pipe 100 during a cooling process of the hot plate and cool the working fluid 104a to a predetermined temperature. To perform this cooling operation, a first cooling unit 144 and a second cooling unit 146 are installed at the first coolant storage tank 134 and the second coolant storage tank 136, respectively.

[0051] When a cooling process of the hot plate begins, the working fluid 104a flows from the heat pipe 100 and simultaneously, the liquid coolant (not shown) is supplied to the heat pipe 100, preferably at a flow rate equal to that of the working fluid 104a. Therefore, a predetermined amount of liquid coolant may be maintained at a predetermined temperature, e.g., 2 °C to 3 °C, and stored in the first coolant storage tank 134 and the second coolant storage tank 136. In particular, the liquid coolant is stored in the second coolant storage tank 136, which is closer to the inlet side of the heat pipe 100.

[0052] The first cooling unit 144 and the second cooling unit 146 of the fourth embodiment perform the same function as the cooling unit of the second embodiment (124 of FIG. 5). The first cooling unit 144 and the second cooling unit 146 may be integrated into a single cooling unit as illustrated by reference numeral 148. Given the positions of the first coolant storage tank 134 and the second coolant storage tank 136, a liquid coolant flowing into

the second coolant tank 136 necessarily flows through the first coolant storage tank 134. Accordingly, the liquid coolant flowing into the second coolant storage tank 136 has a lower temperature than the working fluid 104a flowing into the first coolant storage tank 134. For this reason, the first cooling unit 144 may have a same or higher cooling efficiency than the second cooling unit 146.

[0053] The outlet of the heat pipe 100 is connected to the first coolant storage tank 134 by an outlet connection pipe 138, the first coolant storage tank 134 is connected to the second coolant storage tank 136 by an intermediate connection pipe 140, and the inlet of the heat pipe 100 is connected to the second coolant storage tank 136 by an inlet connection pipe 142. An outlet fluid control unit 126a is installed in the outlet connection pipe 138. An inlet fluid control unit 128a is installed in the inlet connection pipe 142. Like the outlet and/or inlet fluid control units 126a and 128a, an intermediate fluid control unit 140a may be an automatic valve, a manual valve, an automatic pump, or a manual pump. The outlet, inlet, and intermediate fluid control units 126a, 128a, and 140a are opened when cooling of the hot plate starts and are closed when the cooling of the hot plate is finished or when the hot plate is heated again to bake a new wafer.

[0054] In operation, a cooling process of the hot plate occurs as follows. When cooling of the hot plate starts, all of the fluid control units 126a, 128a, and 140a are opened, and a hot working fluid 104a flows from the heat pipe

100 into the first coolant storage tank 134 via the outlet connection pipe 138. The first cooling unit 144 cools the hot working fluid 104a supplied to the first coolant storage tank 134. The working fluid 104a then flows through the intermediate connection pipe 140 into the second coolant storage tank 136. A liquid coolant supplied to the second coolant storage tank 136 is cooled to a desired temperature by the second cooling unit 146 and then flows into the heat pipe 100 via the inlet connection pipe 142.

[0055] Fluid circulation may be continuously conducted until cooling of the hot plate is completed or may be repeated several times for a predetermined time duration, e.g., 15 seconds, each time. The liquid coolant flowing from the second coolant storage tank 136 into the heat pipe 100 may be maintained at any temperature lower than that of the hot working fluid 104a in the heat pipe 100. However, the temperature of the liquid coolant is preferably lower than about 80 °C. This aspect of the process will be subsequently described in greater detail.

[0056] As described above, while passing through the first and second coolant storage tanks 134 and 136, the hot working fluid 104a is cooled to a previous temperature thereof in the heat pipe 100 before the hot plate was heated. The first coolant storage tank 134 and/or the second coolant storage tank 136 may be used to cool the hot working fluid 104a. More specifically, the hot working fluid 104a may be gradually cooled while passing through both the first and second coolant storage tanks 134 and 136.

Alternatively, the hot working fluid 104a may be cooled to a desired temperature using only one of the first and second coolant storage tanks 134 and 136.

Fifth Embodiment

[0057] As shown in FIG. 8, a baking system according to a fifth embodiment of the present invention is similar to that of the fourth embodiment except that the first coolant storage tank 134 and the second cooling unit 144 are removed from the subsidiary cooling system of the baking system in the fifth embodiment.

[0058] In FIG. 8, a coolant storage tank 150 and a cooling system 156 installed at the coolant storage tank 150 correspond to the second coolant storage tank 136 and second cooling system 146 of the fourth embodiment. The coolant storage tank 150 is connected to the outlet side of a heat pipe 100 by an outlet connection pipe 152 and to the inlet side of the heat pipe 100 by an inlet connection pipe 154. A first outlet fluid control unit 152a and a second outlet fluid control unit 152b are sequentially installed in the outlet connection pipe 152, through which a hot working fluid 104a flows from the heat pipe 100 into the coolant storage tank 150. An inlet fluid control unit 154a is installed in the inlet connection pipe 154, through which a cooled liquid coolant flows from the coolant storage tank 150 into the heat pipe 100. The first outlet fluid control unit 152a and the inlet fluid control unit 154a may be automatic valves or manual valves, and the second outlet

fluid control unit 152b may be a pump. Alternatively, the inlet fluid control unit 154a may be a pump.

Sixth Embodiment

[0059] Referring to FIG. 9, in a baking system according to a sixth embodiment of the present invention, a coolant storage tank 160 is installed outside the heat pipe 100. The coolant storage tank 160 is connected to the outlet side of the heat pipe 100 by an outlet connection pipe 162 and to the inlet side of the heat pipe 100 by an inlet connection pipe 164. The hot working fluid 104a flows from the heat pipe 100 into the coolant storage tank 160 via the outlet connection pipe 162. The hot working fluid 104a is cooled while passing through the coolant storage tank 160. The cooled working fluid 104a is then returned to the heat pipe 100 via the inlet connection pipe 164. An outlet fluid control unit 162a is installed in the outlet connection pipe 162. An inlet fluid control unit 164a is installed in the inlet connection pipe 164. The outlet fluid control unit 162a and the inlet fluid control unit 164a may be automatic valves, manual valves, or pumps. A cooling system 160b is installed under the coolant storage tank 160 and a subsidiary heater 160a is mounted on the coolant storage tank 160. The cooling system 160b performs the same function as the foregoing cooling systems. Alternatively, the subsidiary heater may be installed in the inlet connection pipe 164 between an inlet of the heat pipe 100 and the

subsidiary cooling system 160 to heat a fluid flowing through the inlet connection pipe 164.

[0060] The subsidiary heater 160a is used to heat the top surface S1 of the heat pipe 100, i.e., the hot plate surface, along with the heater 102 installed under the heat pipe 100. In operation, when a heating process of the top surface S1 of the heat pipe 100 starts, unlike in the previous embodiments, the outlet fluid control unit 162a and the inlet fluid control unit 164a remain open in the same manner as when the top surface S1 is cooled. Accordingly, the heater 102 heats some of the working fluid 104a in the heat pipe 100, and the subsidiary heater 160a heats the working fluid 104a in the coolant storage tank 160. The subsidiary heater 160a facilitates heating of the top surface S1 of the heat pipe 100 and reduces a time necessary to heat the top surface S1.

[0061] Hereinafter, simulation results showing a cooling efficiency of baking systems of the present invention will be described.

[0062] In the simulation, the baking system shown in FIG. 4 as used as a simulation model and the conventional baking system shown in FIGS. 15 through 17 was used as a contrastive example (hereinafter, referred to as the “contrastive baking system”). In the simulation, a top surface of a heat pipe, i.e., a hot plate, included in the baking system of the present invention, and a hot plate of the contrastive baking system were heated to a temperature of 150 °C and then cooled to a temperature of 100 °C.

[0063] FIGS. 15 and 16 illustrate a partial front view and a plan view, respectively, of a hot plate 200 of the contrastive baking system, in which a first cooling line 206 and a second cooling line 208 for supplying liquid coolant, such as water, are buried. FIG. 15 illustrates a left half of the hot plate 200, wherein the first cooling line 206 is buried. FIG. 16 illustrates a plan view of the entire hot plate, in which the first cooling line 206 and the second cooling line 208 are buried.

[0064] In FIG. 15, reference numerals 202 and 204 are a heater and a lower plate, respectively. In addition, reference character Lc denotes a central line that bisects the hot plate 200 shown in FIG. 16.

[0065] FIG. 17 illustrates a partial front view of the contrastive baking system, in which cooling lines 210 for supplying cooling water are buried only in a lower plate 204 under a heater.

[0066] FIGS. 10 through 14 are graphs showing simulation results of the contrastive baking system. FIGS. 18 through 20 are graphs showing simulation results of the baking system according to the first embodiment of the present invention.

[0067] Specifically, FIGS. 10, 11, 13, and 14 show variation of average temperature and greatest temperature deviation, versus time, of a hot plate surface of the contrastive baking system. FIG. 10 shows a case where the hot plate is cooled naturally (hereinafter, Example 1). FIG. 11 shows a case where the hot plate is cooled by supplying cooling water at a

temperature of 23 °C to each of a first cooling line 206 and a second cooling line 208 at a rate of 1.5 liters per minute (total 3 liters/min) (hereinafter, Example 2). FIG. 13 shows a case where the hot plate is cooled by supplying air at a temperature of 23 °C, instead of cooling water, to each of the first cooling line 206 and the second cooling line 208 (hereinafter, Example 3). FIG. 14 shows a case where the hot plate is cooled by supplying cooling water at a temperature of 18 °C to each of cooling lines 210 buried in a lower plate 204 installed under the heater 202, at a rate of 1.5 liters per minute (total 3 liters/min) (hereinafter, Example 4). In addition, FIG. 12 shows an amount of time necessary to stabilize the temperature in Example 2.

[0068] Reference characters G1 of FIG. 10, G3 of FIG. 11, G5 of FIG. 12, G7 of FIG. 13, and G9 of FIG. 14 indicate first, third, fifth, seventh, and ninth curves, respectively, showing a variation of average temperature of the top surface of the hot plate 200 with time during a cooling process. Reference characters G2 of FIG. 10, G4 of FIG. 11, G6 of FIG. 12, G8 of FIG. 13, and G10 of FIG. 14 indicate second, fourth, sixth, eighth, and tenth curves showing a variation of greatest temperature deviation of the hot plate with time during the cooling process.

[0069] Referring to the first and second curves G1 and G2 of FIG. 10, in Example 1, it took 50 minutes to cool the hot plate from 150 °C to 100 °C,

and the greatest temperature deviation of the hot plate 200 ranged from about 0.2 °C to 0.3 °C.

[0070] Referring to the third curve, G3 of FIG. 11, in Example 2, it took only about 10 seconds to cool the hot plate 200 from 150 °C to 100 °C. However, as shown by the fourth curve G4, the greatest temperature deviation of the hot plate 200 had a very high value ranging from 70 °C to 80 °C.

[0071] As a result, in Example 2, as shown in the fifth and sixth curves G5 and G6 of FIG. 12, it took about 5 minutes to stabilize the temperature after the hot plate 200 was cooled to 100 °C.

[0072] Next, referring to the seventh and eighth curves, G7 and G8 of FIG. 13, in Example 3, it took a long time to cool the hot plate 200 from 150 °C to 100 °C, and the greatest temperature deviation of the hot plate 200 is expected to be 1.4 °C or more.

[0073] Referring to the ninth and tenth curves, G9 and G10 of FIG. 14, in Example 4, it took about 95 seconds to cool the hot plate 200 from 150 °C to 100 °C, and the greatest temperature deviation was almost 8 °C. Further, it took about 4 minutes and 20 seconds to stabilize the temperature.

[0074] Meanwhile, FIGS. 18 through 20 are graphs showing simulation results of the baking system according to the first embodiment of the present invention. Eleventh and twelfth curves G11 and G12 of FIG. 18 show a variation in average temperature and greatest temperature deviation of the

top surface of a hot plate, respectively, with time in a case where a liquid coolant at a temperature of 23 °C circulates three times at 15-second intervals (hereinafter, Example 5).

[0075] In FIG. 19, thirteenth and fourteenth curves G13 and G14 show a variation in average temperature and greatest temperature deviation of the top surface of the hot plate, respectively, with time in a case where a liquid coolant at a temperature of 50 °C circulates four times at 15-second intervals (hereinafter, Example 6).

[0076] In FIG. 20, fifteenth and sixteenth curves G15 and G16 show a variation in the average temperature and greatest temperature deviation of the top surface of the hot plate, respectively, with time in a case where a liquid coolant at a temperature of 80 °C circulates six times at 15-second intervals (hereinafter, Example 7).

[0077] Referring to the eleventh and twelfth curves G11 and G12 of FIG. 18, in Example 5, the hot plate was cooled to a temperature of 100 °C within 40 seconds, and the greatest temperature deviation ΔT of the hot plate was $\Delta T < 0.4$ °C at the end of each interval.

[0078] Further, referring to the thirteenth and fourteenth curves G13 and G14 of FIG. 19, in Example 6, the hot plate was cooled to a temperature of 100 °C within 45 seconds and the greatest temperature deviation ΔT of the hot plate was $\Delta T < 0.2$ °C at the end of each interval.

[0079] In addition, referring to the fifteenth and sixteenth curves G15 and G16 of FIG. 20, in Example 7, the hot plate was cooled to a temperature of 100 °C within 75 seconds, and the greatest temperature deviation ΔT of the hot plate was ΔT < 0.2 °C at the end of each interval.

[0080] The following Table summarizes the foregoing simulation results on cooling of the hot plates of the contrastive baking system and the baking system of the present invention. In the Table, System 1 indicates the baking system of the present invention, and System 2 indicates the contrastive baking system. In addition, a category entitled "the other" represents a case where cooling water is maintained at a temperature of 18 °C in Example 2.

Table

Content		Cooling time (150°C ->100°C)	The greatest temperature deviation (ΔT) (°C)	Temperature stabilizing time (ΔT < 1 °C)
System 1		90 seconds	0.2	1.5 minutes
System 2	Example 1	50 minutes	0.2	50 minutes
	Example 2	10 seconds	78	5 minutes
	Example 3	Long	1.4	-
	Example 4	95 seconds	8	4 and 1/3 minutes
	The other	10 seconds	80	-

[0081] As shown in the Table, in the contrastive baking system (System 2), in the cases where the hot plate was cooled using cooling water (Examples 2 and 4 and the other), the cooling time was shorter (Example 2 and the other) or similar (Example 4) but the temperature deviation ΔT was high and a longer amount of time was necessary to stabilize the temperature

of the hot plate, as compared with the baking system of the present invention (System 1).

[0082] More specifically, in the baking system of the present invention (System 1), the cooling time was similar or slightly longer and the temperature stabilizing time was shorter than in the contrastive baking system and the temperature deviation was the same as in a natural cooling method (Example 1).

[0083] Meanwhile, in Example 1 using the natural cooling method, the cooling time and the stabilizing time were much longer than in the baking system of the present invention. Therefore, despite the small temperature deviation, Example 1 is not suitable for practical use.

[0084] As a result, by analyzing the simulation results, it may be seen that the baking system of the present invention performed better than any contrastive baking system in consideration of overall productivity, cooling effect, and temperature uniformity.

[0085] As described above, the baking system of the present invention includes a heat pipe, a top surface of which is used as a hot plate where a wafer to be baked is loaded, and on sides and a ceiling of which wicks for supplying a working fluid are installed. Thus, when the top surface is cooled, the working fluid is uniformly and rapidly supplied to the entire ceiling of the heat pipe, thus uniformly cooling the entire top surface. The top surface is cooled by evaporating the working fluid supplied to the ceiling of

the heat pipe. Therefore, a time required for stabilizing the temperature of the hot plate surface may be significantly reduced as compared with conventional systems using circulation of cooling water.

[0086] Further, the heat pipe is connected to a subsidiary cooling system, which is used to circulate a working fluid through the heat pipe to cool the top surface. The subsidiary cooling system includes a coolant storage tank, which is filled with a predetermined amount of liquid coolant to be exchanged with the working fluid to cool the top surface, and a cooling unit, which prevents an increase in temperature of the liquid coolant due to inflow of the working fluid. In addition, the coolant storage tank may further include a pressurizing unit, a second cooling system, or a subsidiary heater, if necessary. The subsidiary cooling system is able to maintain the working fluid in the heat pipe at a low temperature during cooling of the top surface of the heat pipe, thus improving the cooling efficiency of the heat pipe. Also, if the coolant storage tank includes a subsidiary heater, a time required for heating the top surface of the heat pipe, i.e., a hot plate surface, may be reduced to improve semiconductor device manufacturing productivity.

[0087] Illustrative embodiments of the present invention have been disclosed herein and, although specific terms are employed, they are used and are to be interpreted in a generic and descriptive sense only and not for purpose of limitation. For example, a coolant storage unit with a subsidiary heater for heating a liquid coolant can be further used if necessary, in addition to a

coolant storage unit with a cooling unit. Accordingly, it will be understood by those of ordinary skill in the art that various changes in form and details may be made without departing from the spirit and scope of the present invention as set forth in the following claims.